SEMI SOLID METAL POURING TEMPERATURE EFFECTS ON MECHANICAL PROPERTIES OF AL-SI ALLOY

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ABSTRACT

In this study, mechanical properties and morphology study of semi-solid metal Al-Si alloy casting was investigated. The sand castings were conducted at three different pouring temperatures. The pouring temperatures for the investigation were 620°C, 640°C and 695°C. The three different samples were tested for their properties such as strength, hardness and the microstructure. Tensile test was conducted using Shimadzu Universal Testing Machine. Hardness was measured by Matsuzawa Rockwell Hardness Testing machine. Microstructure of cast samples were observed using LEICA DME working microscope. The different pouring temperatures caused different cooling rates on the cast samples. The results and observation indicates that a lower temperature produced good quality castings with the maximum values of strength and hardness of 124.34 N/mm^2 and 62.3 respectively. From metallographic study, primary phase of cast sample at the lower pouring temperature was globular structure while dendrite structure occurs due to a higher pouring temperature. The lower pouring temperature provides a finer microstructure and high hardness samples due to faster cooling rate produced at lower pouring temperature.

ABSTRAK

Dalam kajian ini, sifat-sifat mekanikal dan kajian morfologi logam separuh pepejal tuangan aloi Al Si telah disiasat. Penuang-penuang pasir telah dijalankan di tiga perbezaan suhu tuangan.. Suhu-suhu tuangan untuk siasatan merupakan 620°C, 640°C and 695°C. Tiga contoh lain diuji untuk hartanah mereka seperti kekuatan, kekerasan dan mikrostruktur. Ujian tegangan telah dijalankan menggunakan Shimadzu Universal Testing Machine. Kekerasan telah disukat oleh mesin Matsuzawa Rockwell Hardness Testing. Mikrostruktur sampel-sampel tersebut diperhatikan menggunakan LEICA DME mikroskop bekerja. Perbezaan suhu-suhu tuangan menyebabkan kadar penyejukan berbeza pada sampel-sampel tuangan. Keputusan-keputusan dan pemerhatian menunjukkan bahawa satu suhu lebih rendah menghasilkan acuan-acuan berkualiti baik dengan nilai-nilai maksimum kekuatan dan kekerasan 124.34 N/mm^2 dan 62.3 masing-masing. Dari kajian metalografik, fasa primer sampel tuangan lebih rendah suhu tuangannya, ada struktur bulat terlihat manakala struktur ranting berlaku disebabkan oleh suhu tuangan yang lebih tinggi. Suhu tuangan yang lebih rendah menyediakan satu mikrostruktur lebih baik dan kekerasan tinggi disebabkan kadar penyejukan lebih cepat pada suhu tuangan yang lebih rendah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST IF SYMBOLS

%	Percent
°	Degree
σ	Yield stress
α	Alpha

LIST OF ABBREVIATIONS

Al-Si	Aluminium Silicon
SSM	Semi solid metal
Al	Aluminium
Si	Silicon
Sn	Synthium
Pb	Plumbum
Mg	Magnesium
Fe	Ferum
Ti	Titanium
Mn	Manganese
Zn	Zinc
Ni	Nickel
Cr	Chromium
Cu	Copper
V	Vanadium
Co	Cobalt
wt	Weight percentage
HPDC	High pressure die casting
CACs	Charge air coolers
ASME	American Society for Testing and Materials
DTA	Differential Thermal Analysis
O.B.B	Olivin Oil Base
CNC	Computer Numerical
UTS	Ultimate Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Semi solid metal (SSM) processing was discovered by Spencer *et al*. in early 1970s when he investigating hot tearing with a rheometer and this process was put into commercial production by 1981 (Lashkari *et.al*., 2006). Semi-solid metal process is a recent casting that combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy.

In semi-solid metal casting, metal is melted at temperature where slurry remains at a temperature between the solid and liquid state. The ideal temperature is up to 10°C to 660°C which the metal is in a slurry state which is 30% to 60% solid. When it enters the die, the metal which is consist of liquid and solid components is stirred so that the all the dendrites are crushed into fine solids, and when cooled in the die, it developed into fine-grained structure. In this state the metal is further process into the desired castings. To maintain uniform structure and quality of the castings, care must be taken to homogeneously distribute the solid metal without liquid is segregated.

Nearly 30 years of work and effort have been invested in the field of semisolid processing and the increase in interest in this field has been marked by eight international conferences. Semisolid processing is rivalling other manufacturing routes for military, aerospace and most notably automotive components. Europe was produces the part for automotive such as suspension parts, engine brackets and fuel rails. Examples in the USA include mechanical parts for mountain bikes and snowmobiles, while in Asia there is concentration on the production of electronic components such as computer notebook cases and electrical housing components.

1.2 IMPORTANCE OF STUDY

This study was significant because of several causes:

(i) Focusing on the mechanical properties of casting part with different processing temperature.
(ii) Determination of mechanical properties such as tensile strength, yield strength and hardness

1.3 PROBLEM STATEMENTS

Semi-solid metal (SSM) process is a recent casting which combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy. For an engineer, the knowledge and understanding of casting parameters in casting different metals and alloys is as significant as the cast products (Ndaliman *et.al*, 2007).

To produce good quality in castings, semi-solid Al-Si alloy at lower temperature had been choose due to their strength and hardness. When pouring temperature is lower, the mould cavity will not fill the gate or riser will solidify rapidly (Lancer, 1981). At contrast, at higher pouring temperatures causes shrinkage of the casting and mold warping (Grill, 1982). In the current study, the effect of different pouring temperature on mechanical properties of semi-solid Al-Si alloy has been studied.

1.4 OBJECTIVE OF STUDY

The objective of this project is to investigate the effect of different pouring temperatures on the mechanical properties of the material.

1.5 SCOPE OF THE STUDY

The work scopes included in this project were:

(i) To conduct sand casting at different pouring temperatures of semi-solid metal A356 alloy.
(ii) To conduct metallographic study of cast Al-Si Alloy sample using LEICA DME working microscope.
(iii) To conduct tensile test at room temperature for cast Al-Si alloy samples using Shimadzu Universal Testing Machine.
(iv) To measure hardness properties on casting Al-Si Alloy examples using Matsuzawa Rockwell Hardness Testing Machine. .

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this literature review, metal casting process and properties of Aluminium Silicon alloy were reviewed. By reviewing on the others author review, the effect of pouring temperature on semi solid microstructure and mechanical properties of Al-Si alloy was determined.

2.2 SEMI SOLID METAL

Semi-solid metal (SSM) process is a recent casting which combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy. Semi solid occurs between the liquidus and solidus of the alloy, a temperature range in which the fluidity of the molten metal can change greatly. This SSM processed was first discovered by Spencer et al. during his continuously hot tearing test of solidifying Sn-15% Pb (Lashkari *et.al*., 2006)..

Semi-solid metal processing is a unique manufacturing method to produce near-net shape products for various industrial applications (Fleming, 2006). The aim is to obtain a semi-solid structure free of dendrites which are formed by conventional liquid casting, with the solid present as nearly a spherical form as possible. This semi-solid mixture like a gel or toothpaste flows homogeneously, behaving as a thixotropic fluid with viscosity depending on shear rate and fraction solid (Lashkari *et al*., 2007). There are two different SSM processes which are thixocasting and rheocasting. With thixocasting, a specially prepared billet of solid material with a globular microstructure is reheated into the semi-solid range and formed. Rheocasting involves preparation of a SSM slurry directly from the liquid, followed by a forming process such as high pressure die casting (HPDC).

An overall, all types of materials, whose solidification extends over a temperature range which is mushy zone, are suitable to be SSM processed. This is true for metallic alloys to have a wide solidification range with dendritic growth (Fleming ,1991; Kirkwood,1994; Fan,2001). The mushy zone contains the solid and liquid phase which also known as “the mush”. However, the alloys with narrow solidification range or single point transformation such as eutectic alloys cannot be SSM process.

2.3 ALUMINIUM SILICON ALLOY

Al–Si alloys are widely used in different fields of industry. Various additives are usually used to modify industrial alloys. Nowadays, much attention has been given to unmodified cast alloys, especially to hypereutectic Al–Si alloys. In the same time, the structure and mechanical properties of hypereutectic unmodified cast alloys has been studied for Si content up to 19%. It is only known that increasing the Si content results in an increase of the strength of hypoeutectic alloys and a decrease of the strength of hypereutectic alloys (Stroganov *et al*., 1977; Gupta *et al*., 1999).

In addition to chemical composition, the structural and mechanical properties of alloys depend on many factors act during solidification. The important factors are the structure of the melt, the crystallization rate, and the temperature gradient at the liquid–solid interface.

As a rule these factors are varied simultaneously, giving rise to contradictory information on the structure and mechanical properties of Al–Si alloys. Thus, for example, the yield stress, σ 0.2 was published to increase (Mondolfo, 1976; Gupta *et al.,* 1999) or decrease (Stroganov *et al*., 1977) with increasing content of Si. In order to investigate the influence of the Si content on structure and mechanical properties, it is necessary to prevent contamination by impurities from the crucible and the environment, to maintain constant the superheating of the melt, to have a constant and rather high cooling rate, and effective mixing of the molten alloy.

2.3.1 Phase Diagram Al-Si Alloy

Based on the phase diagram for Al-Si system as show in Figure 2.2 below, it contains a eutectic point at 12.6 wt% Si. The eutectic temperature is 577°C is very low and the Al dissolves a maximum 1.65 wt% Si while the solubility if aluminium in silicon is very low and can be neglected. The slow cooling of Al-Si alloys, starting from the liquid phase, leads to different microstructure being formed depending on whether the silicon content is lower than the eutectic composition (hypoeutectic alloys) or higher than the eutectic composition (hypereutectic) as show in Figure 2.1.

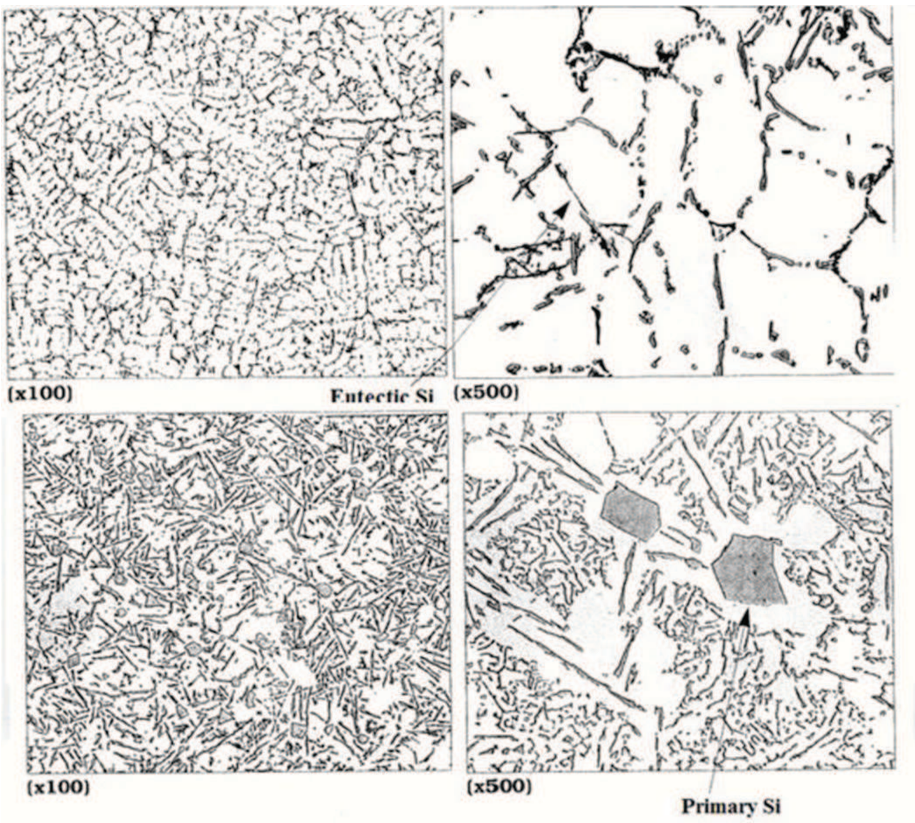

Figure 2.1: Hypeeutetic of Al-Si

(Source: NCMTT, SIRIM BERHAD)

2.3.2 Primary and Eutectic Phase

Al-Si binary alloy is a eutectic system with the eutectic composition at 12.6 wt% Si (Massalski *et al*., 1990) (Fig.2.2). When the Al-Si alloy solidifies, the primary aluminum forms and grows in dendrites or silicon phase forms and grows in angular primary particles (Haizhi, 2002). The eutectic Al-Si phases nucleate and grow until the end of solidification when it reached at the eutectic point. At room temperature, hypoeutectic alloys consist of a soft and ductile primary aluminum phase. It also has a hard and brittle eutectic silicon phase. In hypereutectic alloys, it usually contains coarse, angular primary silicon particles as well as a eutectic silicon phase.

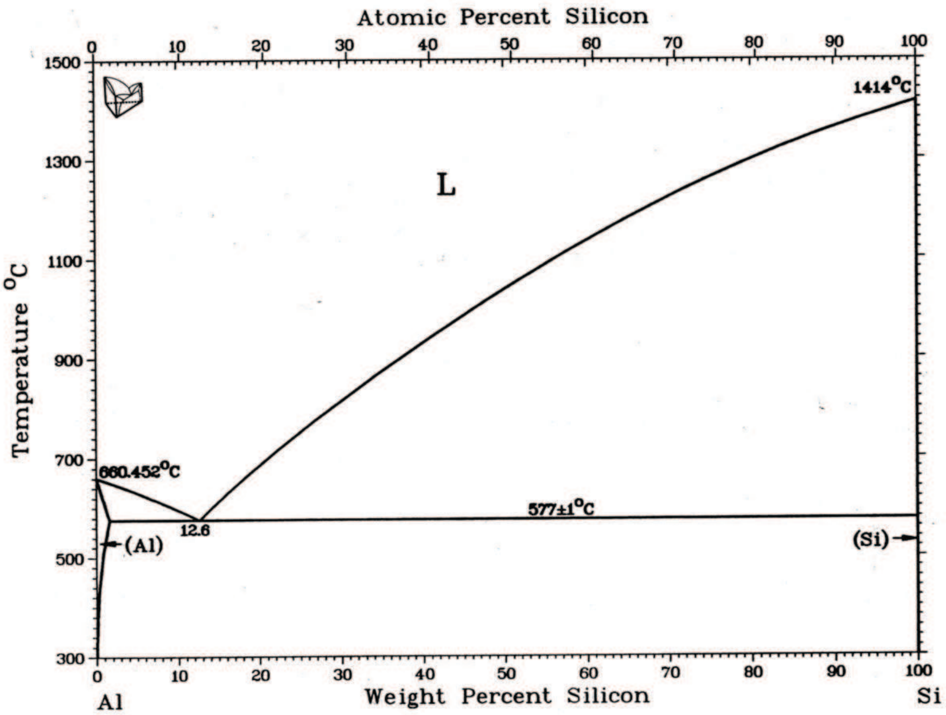

Figure 2.2: The Al-Si binary phase diagrams

(Source: Massalski *et al*., 1990)

The hypoeutectic and hypereutectic Al-Si alloys have both been used as tribological material in engine applications. However, hypereutectic Al-Si alloy can be used to produce engine block without cylinder liner as it has a higher wear resistance resulting from a larger fraction of silicon phase. Usually, the hypereutectic AL-Si alloy engine block surface is electrochemically treated to etch away some of the matrix aluminium alloy so that the eutectic and primary silicon particle can protrude to sustain wear (Haizhi, 2002).

2.3.3 Al-Si Alloy Applications

The applications of Aluminium nowadays are in vehicles cover, chassis, power trains, air conditioning and also in body structure. For a long period, the aluminum casting have been applied to various automobile parts such as engine block, which is the one of the heavier parts in vehicle, is being changed from cast iron to Aluminium casting that give the best result in weight reduction. In power train, aluminum castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission and also other parts like rear axle, differential housings and drive shafts and so on. Aluminium casting in chassis applications are used about 40% of wheels, for bracket, brake components, suspension which are control arms and supports, for steering component such as air bag supports, steering shafts, knuckles, housings, wheels and also for instrument panels (Nayak *et al*., 2011).

Forged wheels have been used where the loading conditions are more extreme and where higher mechanical properties are required. Aluminium alloys have also found extensive application in heat exchangers. In this modern years, high performance automobiles have many individual heat exchangers, e.g. engine and transmission cooling, charge air coolers (CACs), climate control, made up of Aluminium alloys (Miller *et al*.).

Due to its unique properties, Al-Si becomes an important alloy for many commercial automotive applications such as piston, cylinder liners and so on. Al-Si alloy is the most versatile in the production of pistons for automotive engines. Commercial uses for hypereutectic alloys are limited because due to the high Si contents, it difficult Al alloys to cast and machine. When the high Si content is alloyed in Al, it causes a large amount of heat capacity that must be removed from the alloy to solidify it during the casting operation. Between different areas of cast structure, the major variation sizes of the primary Si particle can be seen. It causes the significant deviation in the mechanical properties for the specimen. To accomplish the better hardness and wear resistance, the primary of the Si crystals must be refined (Nayak *et al*., 2011).

From these reason, hypereutectic alloys are not very cost-effective to fabricate because they have a broad range of solidification resulting in poor castability and requires extra foundry processes to control the microstructure and high heat of fusion. In the other hand, the hypoeutectic and eutectic alloys are very widespread in industries. This is because:

(i) More efficient to produce by casting
(ii) Simpler to control the cast parameters
(iii)Easier to machine than hypereutectic.

But, most of them are not appropriate for high temperature applications, such as in the automotive field, for the reason that their mechanical properties, such as tensile strength, are not as high as anticipated in the temperature range of 250°C - 400°C (Lee *et al*.).

2.4 ALUMINIUM CASTING PROCESS

Casting is a manufacturing process where a solid is melted, heated to proper temperature which sometimes treated to modify its chemical composition, and is then poured into a cavity or mold, which contains it in the proper shape during solidification. Thus, in a single step, simple or complex shapes can be made from any metal that can be melted. The resulting product can have virtually any configuration the designer desires.

Nowadays, there are a large number of industrial casting processes. These can be classified based on the mould material, method of producing the mould and the pressure on molten metal during filling which are gravity, centrifugal force, vacuum, low pressure and high pressure. There are three main processes of casting which are permanent metal mould, sand casting and die casting.

Permanent metal moulds was used in gravity and pressure die casting processes, suitable for producing a large number of parts. In expendable mould processes which are sand, shell and investment, a new mould is required for every casting or a bunch produced in the same mould. Expendable mould can be made using either permanent pattern or expandable pattern. Permanent pattern can be made from wood, metal, or plastic (Ravi, 2006).

Sand casting is process which sand mixed with binders and water is compacted around wood or metal pattern halves to produce a mould. The mould is removed from the pattern, assembled with cores, if necessary, and metal is poured into the resultant cavities. After cooling, mould is broken to remove the casting. This process is suitable for a wide range of metals which both ferrous and non-ferrous, size and shape complexity.

The sand casting process usually chosen for the production of (1) small quantities of identical castings, (2) complex castings with intricate cores, (3) large castings, and (4) structural castings (Smith *et al*., 2006). The advantages of the sand casting is almost any metal can be cast which is no limit to part size, shape, weight and it is low tooling cost to do this laboratory (Kalpakjian *et al*., 2006). Basically, the common method of proceed in sand casting process must include pattern making, mould making, melting and pouring of metal, cooling and solidification and lastly is the cleaning process and the inspection.

In die casting, identical parts are cast at maximum production rates by forcing molten metal under consideration pressure into metal molds. Two metal die halves are securely locked together to withstand high pressure. The molten aluminum is forced into the cavities in the dies. The dies are unlocked when the metal has solidified to eject the hot casting. The casting cycle is repeated after the die halves are locked together again. The advantages of die casting are (1) parts die cast are almost completely finished and can produce at high rates, (2) dimensional tolerance of each cast part can be more closely held than with any other major casting process, (3) smooth surfaces on he casting are obtainable, (4) rapid cooling of the casting produce a fine-grain structure, and (5) the process can be automated easily (Smith *et al*., 2006).

2.5 POURING TEMPERATURE ON SEMI-SOLID MICROSTRUCTURE

In studying the effect of pouring temperature on the morphology of primary Al particles and the rheological behavior of microstructures for semi-solid Al–Si A356 alloy, Lashkari (2006) reported that dendrite primary Al structures formed at the highest pouring temperatures of 675°C –695°C have the greatest viscosity numbers. They are almost two orders of magnitude greater than those for rosette structure formed at moderate pouring temperatures of 630°C –645°C. The viscosity of the dendrite primary Al structures is three orders of magnitude greater than those for globular morphology formed at the lowest pouring temperature of 615°C (Lashkari *et al*, 2006).

Figure 2.3 shows the semi-solid microstructures of A356 alloy obtained at the different pouring prepared by low superheat pouring and slightly electromagnetic stirring researched by Liu *et al*;(2006). The microstructure of A356 of semi-solid A356 alloy poured at 650°C is shown in Fig. (a). It is seen that the morphology of primary phase is mainly rossete-like, and a few globular-like and particle-like coarse grains are observed. The microstructure of semi-solid A356 alloy poured at 630°C is shown in Fig. (b) which contains of globular-like and particle-like primary phase and a few rosette-like fine grains. The microstructure of semi-solid A356 alloy poured at 615°C in shown in Fig. (c), and basically consists of globular-like and particle-like primary phase with small grain size (Liu *et al*., 2006).

It seem that, under the electromagnetic stirring, the morphology of primary phase obtained from semi-solid A356 alloy is changed from rosette-like to particle like. Besides, the grain size is decreased as pouring temperature of liquid alloy decrease (Liu *et al*., 2009). It is feasible to refine grain size and improve grain morphology by controlling pouring temperature or make use of low superheat pouring (Flemings, 1991 and Liu *et al.,* 2006).

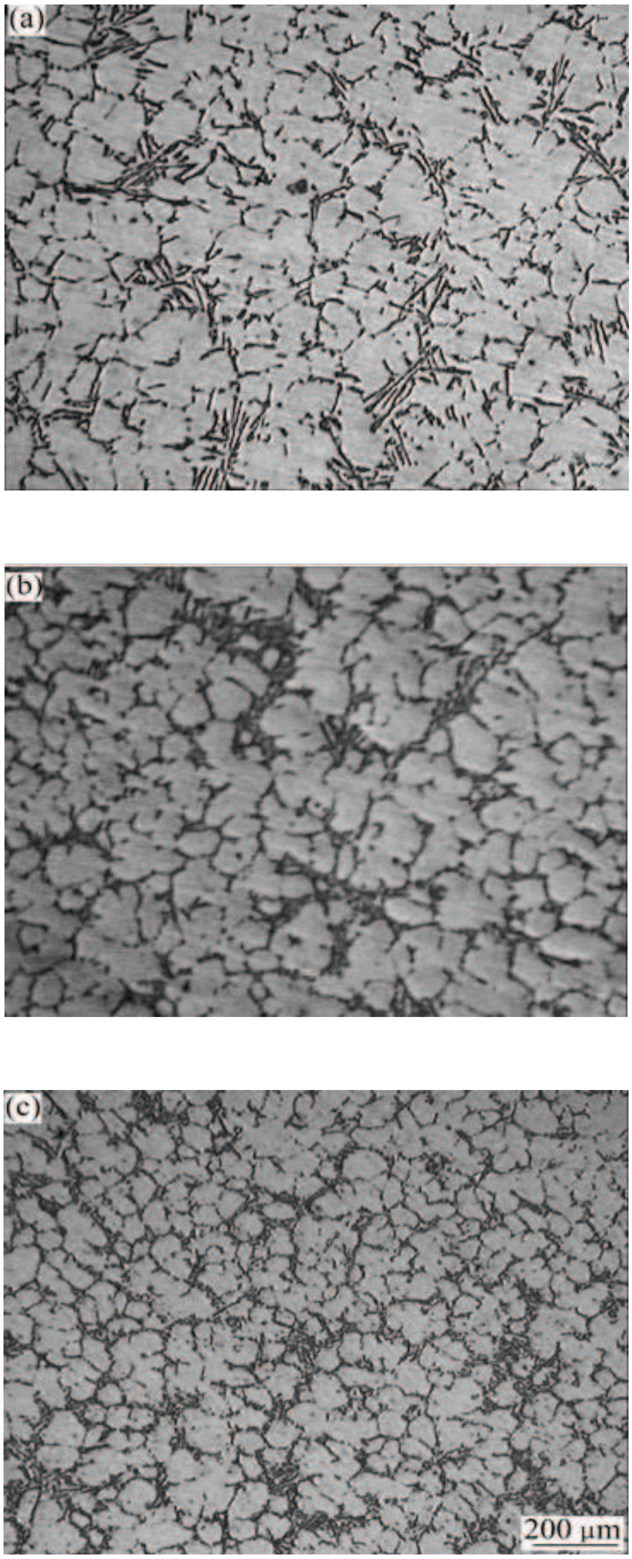

Figure 2.3: Morphologies of primary phase in A356 alloy obtained at different pouring temperatures: (a) 650°C; (b) 630°C; and (c) 615°C

(Source: Liu *et al*., 2006)